Monitoring the head injured patient

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Introduction

There are many parameters that can be used to monitor the status of a head injured patient. Of those that are most commonly used the most important appear to be intracranial pressure (ICP) and cerebral perfusion pressure (CPP). Since the landmark paper of Lundberg (1960) which first demonstrated the clinical use of ICP monitoring it has grown to become a standard technique in the management of severely head injured patients. The primary brain injury, regardless of its cause, is normally irreversible. Therefore the major factor in producing any improvements in outcome must be targeted at preventing secondary damage. There are only a few variables which can be easily treated and, due to the importance of intracranial hypertension and the significance that it has on outcome, both intracranial pressure and cerebral perfusion pressure have gained importance in patient management.

Methods of analysing ICP data

Although the American guidelines for head injury management suggest a minimum target level of 70 mmHg this may not be an absolute threshold level where there is a distinct change in the likelihood of a favorable outcome. This may be particularly so in children where it is known that the arterial pressure is lower than that of adults. In an attempt to try and define more precisely the optimal target values of ICP and CPP, a new form of analysis has been undertaken. Data was collected from severely head injured patients, defined as a Glasgow Coma Sum of less than or equal to eight on admission to the Neurosurgical Centre at Newcastle General Hospital between November 1989 and January 1997, who required intracranial pressure monitoring as a routine part of their clinical management. ICP monitoring was commenced as soon as practically possible after admission and was continued for as long as clinically indicated. The intracranial pressure, arterial pressure and cerebral perfusion pressure were recorded every two minutes from a total of three hundred and eighteen patients. Of these, twenty seven were either lost to follow up or had no information as to the CT scan classification and so were excluded from the analysis. Of the remaining two hundred and ninety one patients, 213 (73.2%) were male and 78 (26.8%) were female. The ages ranged from 3 months to 83 years of age.

The recording periods ranged from 5.7 hours up to one extreme case of 197 hours. The average length of recording was 42 hours. Outcome was assessed using the Glasgow Outcome Scale at six months post discharge.

Classification of injury and patient population

It is important to recognize that differences exist between adults and children in the management of head injuries, children are not “small” adults and all aspects of adult head injury management

Table 1. CT scan classification

Category		Definition
Diffuse Injury I	DI I	No visible intracranial pathology seen on CT scan
Diffuse Injury II	DI II	Cisterns are present with midline shift 0-5mm and/or lesion densities present
Diffuse Injury III	DI III	cisterns compressed or absent with midline shift 0-5mm, no high - or mixed - density lesion > 25cc
Diffuse Injury IV	DI IV	midline shift > 5mm, no high or mixed density lesion > 25cc
Evacuated mass lesion	EML	any lesion surgically evacuated
Non-evacuated mass lesion	NEML	high or mixed density lesion > 25cc, not surgically evacuated.

cannot be extrapolated to children (Brookes, M. et al. 1990; Teasdale, G.M. et al. 1990; Miller, J.D. 1994). For these reasons the analysis of the results has been separated into an adult group (age over 16 years) and a paediatric group (age 0 to 16 years). The Marshall CT scan classification system (1991, table 1) has clear definitions for the diffuse injury categories one to four; the two other major groupings of evacuated mass lesions and non-evacuated mass lesions pose more of a problem. The class into which patients will fall depends upon clinical judgement to a certain extent, and there is no separation of subdural, extradural and intracerebral haemorrhages. Furthermore patients who are initially managed conservatively may later proceed to surgery. Despite these shortcomings this method was used to classify injury.

Length and number of recordings
Adults

There were 207 cases in the adult group and the average age for this group was 38.5 years. Recordings varied in length from 5.7 to 197 hours with a mean value of 37.9 hours. The mean recording length and standard deviation was similar for each outcome category. This indicates that monitoring times for poor outcomes were not significantly longer than for good outcomes. This allows comparisons to be made between the outcomes from each of the TCDB categories in relation to the values of ICP, MAP and CPP There were two patients who suffered severe brain stem injuries without other visible pathologies on CT scan and they have been excluded from the analysis of each of the TCDB categories.

Children

There were eighty four cases in the pediatric group, and the average age was 9.7. Recordings varied in length from 6.3 to 173 hours with a mean value of 53.1 hours. The good recoveries, moderate disability and those that died had similar recording lengths. Only those that were severely disabled had a much longer monitoring period.
Table 2 describes the outcomes for both adult and pediatric cases.

Relationship between ICP, CPP and outcome

In order to relate the values of ICP and CPP to outcome, the minimum CPP averaged over any one hour interval and the maximum ICP averaged over an hour were calculated.

Table 2. Summary of outcomes in both adult and pediatric cases

	Adult		Pediatric	
Outcome				
Good recovery	52	Independent 113	33	Independent 63
Moderate disability	61		30	
Severe disability	34	Poor 94	10	Poor 21
Vegetative	3		0	
Dead	57		11	
TOTAL	207		84	

Adults

Using this simple summary measure and taking a CPP of 60 mmHg, there is a significant relationship between the independent and poor outcome groups with this stratification ($p=0.009$). There is also a considerable difference between the fraction of patients who made an independent recovery where the CPP was greater than 60 mmHg. With regard to the maximum average ICP over one hour, a level of 30 mmHg also produces a significant difference in outcome category ($p=0.045$). Similarly for ICP, at a level less than 30 mmHg there is a significant difference in outcome ($p=0.045$).

Children

In children, a CPP threshold of 50 mmHg showed a significantly better outcome between the independent and poor outcome groups ($p=0.012$). For ICP there was also a significant relationship at a value of 30 mmHg ($p=0.002$).

Figures 1 and 2 show the minimum averaged CPP and maximum averaged ICP for each of the outcome categories for adults and children

The data corroborates that there is a significantly better outcome in those patients whose minimum averaged CPP over one hour is greater than 60 mmHg in adults and 50 mmHg in children. In addition, for both adults and children where the maximum averaged ICP over one hour is less than 30 mmHg there was a significantly better outcome.

Receiver Operator Characteristic (ROC) curves.

To determine which precise levels of intracranial pressure and cerebral perfusion pressure could best be associated with outcome, the sensitivity and specificity of these variables in relation to outcome Receiver Operating Characteristic (ROC) curves were determined.

When a clinical test which has a binary outcome (the result can be associated with one of two possible outcomes) and the population being studied can also be divided into one of two states (say disease present and disease absent), the sensitivity of the test is defined as the ratio of true positive results to the total number of results where disease is present:

$$\text{Sensitivity} = \text{TPR} = \frac{N_{TP}}{N_{TP} + N_{FN}}$$

and the specificity is defined as the compliment of the false positive ratio (FPR) or the proportion of true negative results to the total number of results where disease is absent:

$$\text{Specificity} = 1 - \text{FPR} = \frac{N_{TN}}{N_{TN} + N_{FP}}$$

Figure 1. Minimum averaged CPP over one hour vs outcome for adults and children

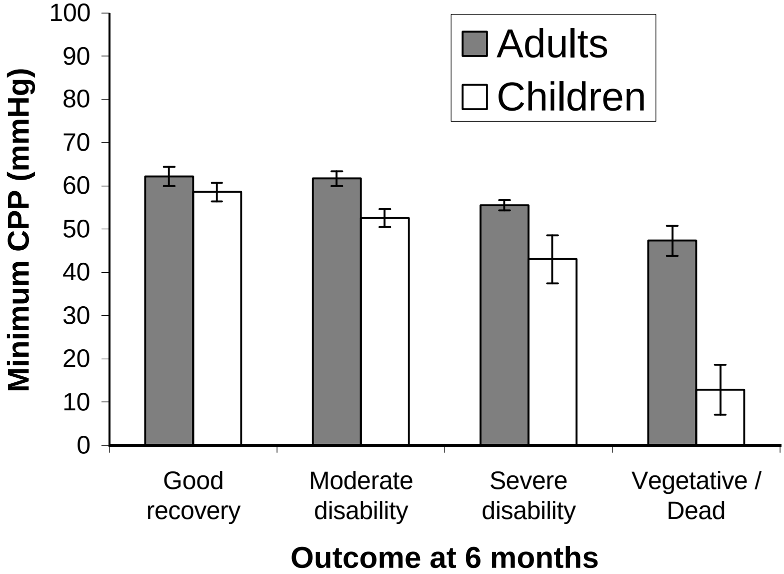
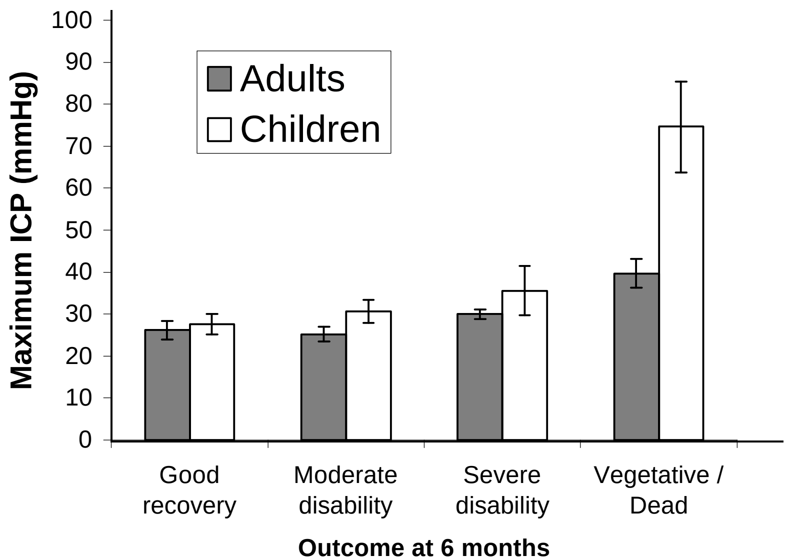


Figure 2. Maximum averaged ICP over one hour vs outcome



ROC curves are created by varying the threshold of the decision making process of a test over a range of values. For each level of the threshold the sensitivity and specificity are calculated. Plotting the sensitivity against the compliment of the specificity (1-specificity). The diagonal on the graph represents the null hypothesis and a curve following this line would demonstrate that the applied test had no more potential of producing a correct answer than one selected by pure chance. An ideal test would hug the ordinate and at a specific value then follow the top of the graph i.e. there would be a clearly defined point below which the test would be very specific (low false positive negative rate) whilst above the point it would become very sensitive (low false negative rate). It is unlikely that any natural system would follow the ideal case and the degree of value of a test can be found by observing how far the curve lies away from the diagonal (curve to diagonal distance = CDD).

By overlaying the ROC curves for each test on the same graph, simple inspection will show which test performs better under different conditions. This method was applied to the results obtained from the ICP and CPP recordings. The hypotheses was that a particular value of either ICP or CPP could be a threshold in determining outcome. If the outcome is categorized into two discrete categories - independent (good recovery, or moderate disability) and dependent (severely disabled, vegetative or dead) then for any arbitrary value of CPP the sensitivity and specificity can be calculated. By varying this threshold value from 30 to 100 mmHg in a 1 mmHg interval the sensitivity and specificity were calculated for each level and a ROC curve created. ROC curves were then also created for ICP over the threshold range of 0 to 90 mmHg.

The distance the curves lie away from the diagonal can be estimated from the area under the curve (Zweig 1993). The larger this area then the greater the discriminatory power of the test. Thus one curve which lies completely above another is a better predictor of outcome.

Results

The ICP and CPP ROC curves from the complete data set described above are shown in Figures 2 and 3. Both curves are similar in shape, above the diagonal of equality. The sensitivity is unity for values of CPP below 40 mmHg indicating that this is an important level below which patients will die as there were no vegetative or severely disabled survivors with minimum averaged CPP values below this level.

For ICP the sensitivity did not reach unity until 80 mmHg demonstrating that some patients can have severely raised ICP and still progress to an independent outcome.

For adults the area under the CPP curve was 0.643 and under the ICP curve 0.608. Although the area under the CPP curve is greater it is clear that both these variable influence outcome.

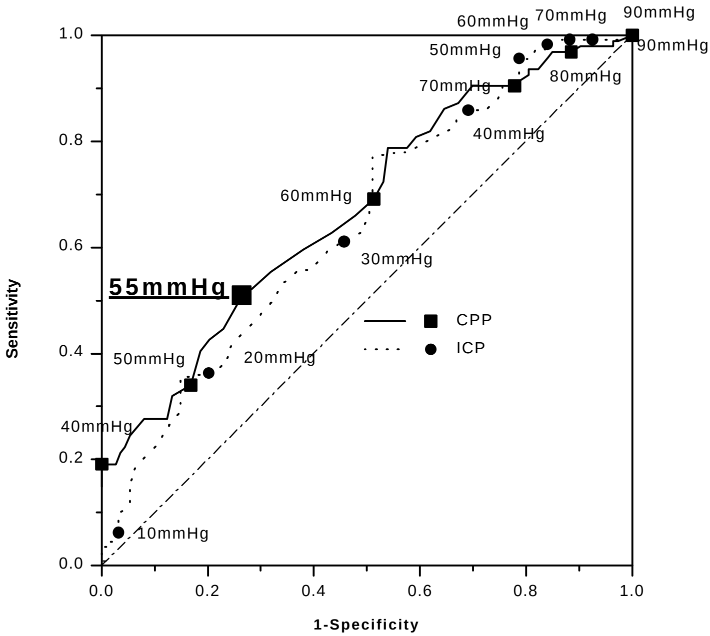
Adults

The curves for both ICP and CPP for the adult cases were created and are shown in Figure 2. The curves are very similar, demonstrating little difference in the determinant power of the two variables. At a value of 40 mmHg the specificity of CPP is 1 i.e. there were no patients with an average CPP over one hour less than 40 mmHg who had an independent outcome. In fact there were none who survived with this level of CPP insult. CDD was maximal at 55 mmHg for adults.

Children

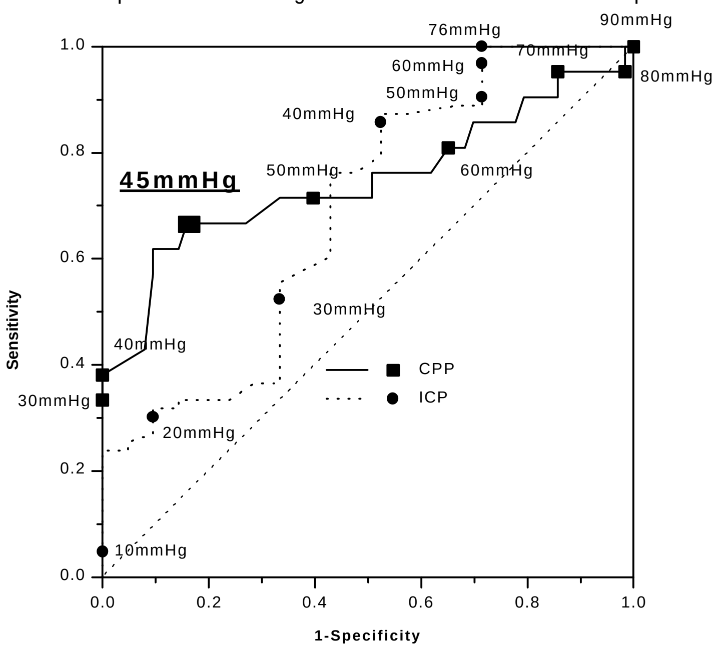
The ROC curves for ICP and CPP from all the paediatric cases are shown in Figure 4. There are significant differences between these curves and those from the adult group. Again the sensitiv-

Figure 3. ROC curves for all adult cases using ICP and CPP as a threshold for independent / poor outcome



Area under curves: CPP = 0.673, ICP = 0.645

Figure 4. ROC curves for all pediatric cases using ICP and CPP as a threshold for independent / poor outcome



Area under curves: CPP = 0.747, ICP = 0.687

ity of ICP starts rising from just under 20 mmHg and steadily increases to a value of 0.85 at 40 mmHg and it continues to rise to a value of 1 at 70 mmHg. For CPP the sensitivity is 0.38 at 40 mmHg and rises sharply to 0.7 at 50 mmHg. At higher values of CPP the sensitivity keeps rising but it does not reach unity until 90 mmHg. The area under the CPP curve (0.747) is greater than that for the ICP curve (0.687), for CPP values under 60 mmHg and for ICP values above 30 mmHg the curves lie further away from the diagonal than those for the adult cases. CDD was maximal at 45mmHg for children.

ROC curves were created for the five main categories of CT scan classification (DI I to III, EML and NEML). From table 3 the minimum CPP the value at which the sensitivity reached unity for Diffuse Injury I group was 81 mmHg and 45 mmHg for adults and children respectively. For adult Diffuse Injury II and II it was lower but for the adult evacuated and non-evacuated mass lesion groups it was higher. This would suggest that the targets for therapy may need to take account of the injury type and that it is not appropriate to consider only one level for all patients.

The analysis of all the adult recordings showed little difference between the curves for ICP and CPP. There were two findings that stood out. First, no patient with an average CPP of less than 40 mmHg survived and secondly, if the minimum averaged CPP over one hour remained over 55 mmHg in adults and 45 mmHg in children the distance of the ROC from the diagonal (null hypotheses) was maximal. Although the value of 70 mmHg was suggested in the American Head Injury Guidelines as a minimum target level of CPP it may be that this is too high, especially in children and that independent outcome can be achieved with these lower levels of perfusion pressure (55 mmHg and 45 mmHg respectively). For Diffuse Injury Types I II and III, there is clear evidence that the minimum CPP over one hour is much more predictive of outcome in comparison to the maximum averaged ICP over one hour. Patients who are classified into the Diffuse Injury Type I should be managed to ensure adequate cerebral perfusion pressure and that close monitoring of the arterial pressure is necessary as the secondary insults in this group that were identified were predominantly caused by reductions in arterial pressure.

The areas under each of the CPP and ICP ROC curves in Table 3 show that only for the pediatric evacuated mass lesion group does the ICP curve have a greater predictive value than that of CPP. This reinforces the significance of CPP management in head injury. However, this should not be at the expense of ignoring ICP. The curves show that there is a relationship between ICP and outcome, it is also clear that CPP plays a more prominent role in that determination and therefore must be closely monitored.

Discussion

Receiver operator characteristic curves are useful in the analysis of data as they can simultaneously display both the sensitivity and the specificity of a diagnostic test. They give a measure of how good the test is in comparison to pure chance and can be used to compare different tests. The need to use ROC analysis arises from the fact that it can be misleading to use a figure such as the conditional probability of a true positive response. This may be biased by extraneous factors and a better index is the sensitivity as it considers both the false negatives and the true positives. By combining the sensitivity with the specificity a ROC curve can give a more accurate picture of how the diagnostic test performs over a range of values and determine whether there is a particular threshold value. This analysis has shown that ROC curves can demonstrate the relationship between ICP, CPP and outcome. By increasing the number of patients within each group it may be possible to more precisely define the levels at

Table 3. Areas under ROC curves

	CPP			ICP		
	Adults	Children	All cases	Adults	Children	All cases
All cases	0.673	0.747	0.636	0.644	0.687	0.586
DI I	0.819	0.950	0.766	0.679	0.650	0.647
DI II	0.695	0.771	0.665	0.674	0.674	0.574
DI III	0.770	0.646	0.711	0.590	0.542	0.601
EML	0.684	0.647	0.653	0.669	0.847	0.650
NEML	0.522	0.856	0.573	0.607	0.635	0.524

which treatment should be targeted and to improve the resolution of the curves.

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